The All-Electric Ship Consortium
Mississippi State University

ONR AEPS S&T Thrust Review

Presented by Michael S. Mazzola

November 7, 2002

Acknowledgements

Faculty:
- J. W. Bruce
- Ben Choe
- Randy Follett
- Mark Halpin
- Georgios Lazerou
- Marshall Molen
- Noel Schulz

Staff:
- Bill Buchanan
- Angela Card
- Jim Gafford
- Jane Moorehead

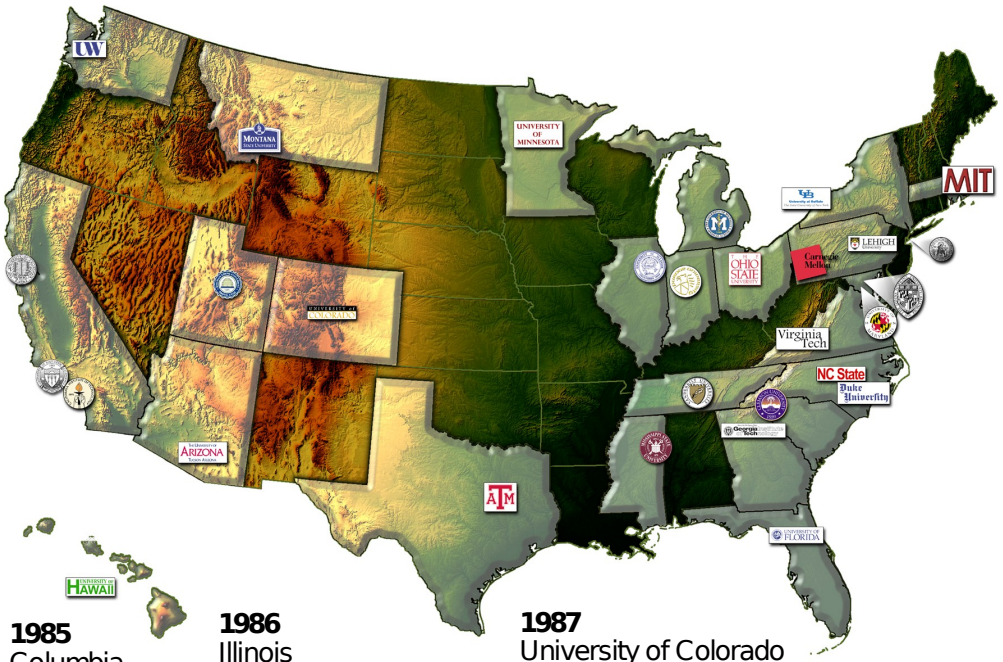
MISSISSIPPI STATE UNIVERSITY

- Established in 1878 as Land-Grant Institution
- University covers 4,200 acres
- Comprehensive Research University
- Enrollment - 16,000
- Faculty - 850

COLLEGE OF ENGINEERING

- Aerospace Engineering
- Agricultural and Biological Engineering
- Chemical Engineering
- Civil Engineering
- Computer Science
- Electrical & Computer Engineering
- Industrial Engineering
- Mechanical Engineering

NSF Engineering Research Centers



1985
Columbia
MIT
Maryland
Harvard
Purdue

1986
Illinois
Brigham Young
Utah
Lehigh
Ohio State
Carnegie-Mellon

1987
University of Colorado
Duke University

1988
Texas A&M
Minnesota
North Carolina State

1990
Carnegie-Mellon
Montana State
Mississippi State

1994
Florida
Cal Tech
Georgia Tech

1996
Arizona
Washington
Michigan
MIT
Southern California

1997
California at Berkeley
University of Illinois
SUNY-Buffalo

1998
Virginia Tech
Clemson
Georgia Tech
Hawaii
Johns Hopkins

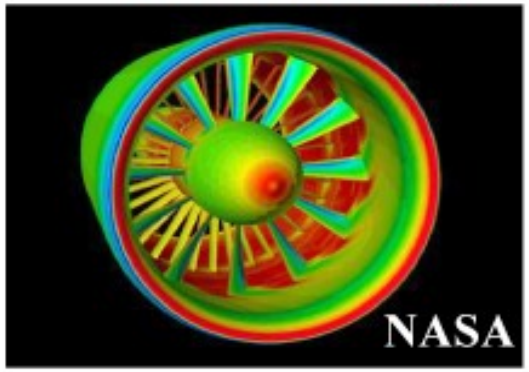
1999
Vanderbilt

NSF Engineering Research Center

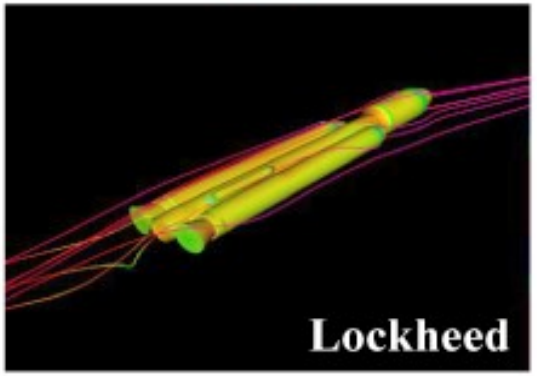
Significant Achievements
Real–World Applications

Mississippi State University

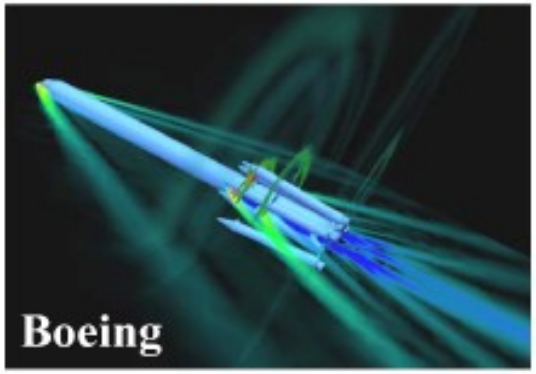
Turbomachinery



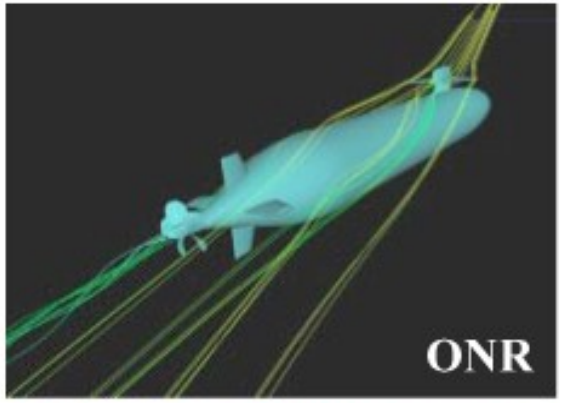
Titan



Delta II

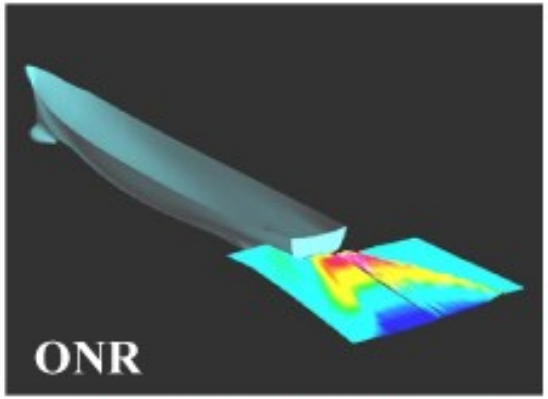


Solving Real–World Problems: Complex Geometry in Relative Motion



Maneuvering Submarine

Propulsor Design



Surface Ship Design

An Overview of the Department of Electrical and Computer Engineering

Degrees offered: BS, MS, Ph.D. in Electrical Engineering and Computer Engineering

Enrollment: Undergraduate –

Electrical Engineering 280

Computer Engineering 320

Graduate - 200

Faculty: 26

Staff: 15

Departmental Emphasis

- Communication Systems
- Control Systems
- Computer & Digital Systems
- Electromagnetic Fields
- Microelectronics
- *Power Systems*
  - *Historically, 3-5 faculty identify with power.*
  - *40-50 seniors self identify as power majors.*
  - *Many alumni work at utilities, in consulting engineering, and in manufacturing, including shipbuilding.*

Mississippi State University

Power and Energy Activities within MSU's Electrical & Computer Engineering Department

Mississippi State University Programs in Electric Power

Major Programs

- Radar Power (SMDC)
- Electric Utilities
- Electric Ship (ONR)
- More Electric Aircraft (AFRL)

Enabling Technologies

- Mississippi Center for Advanced Semiconductor Processing
- MSU High Voltage Laboratory
- Institute of Signal and Information Processing
- Information Sensing Systems Laboratory
- Diagnostic Instrumentation Analysis Laboratory (DOE)

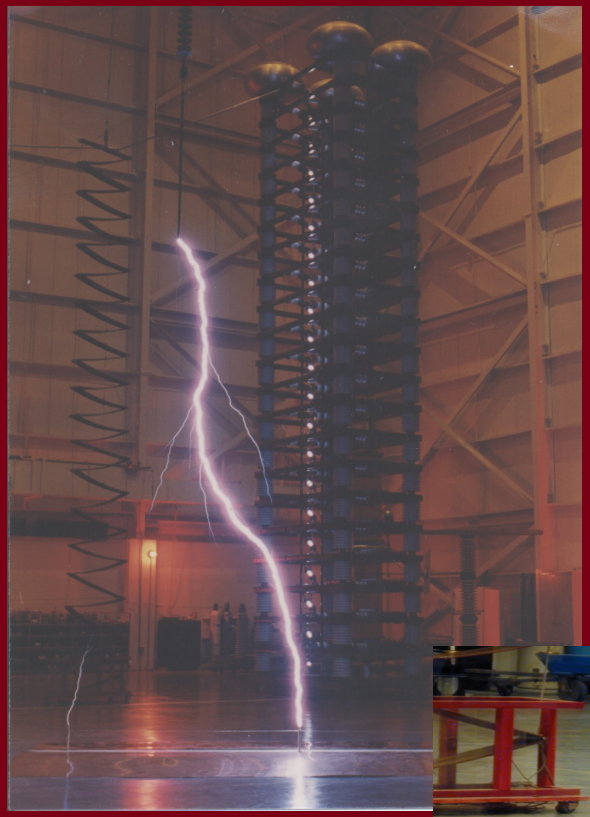
Allied Programs

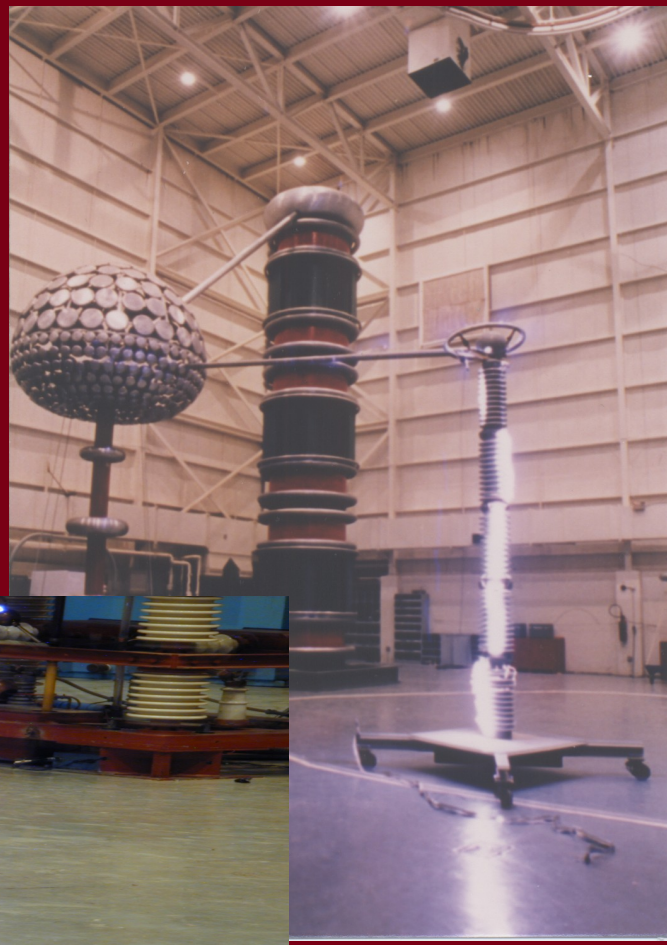
- Center for Advanced Vehicular Studies
- Raspet Flight Laboratory

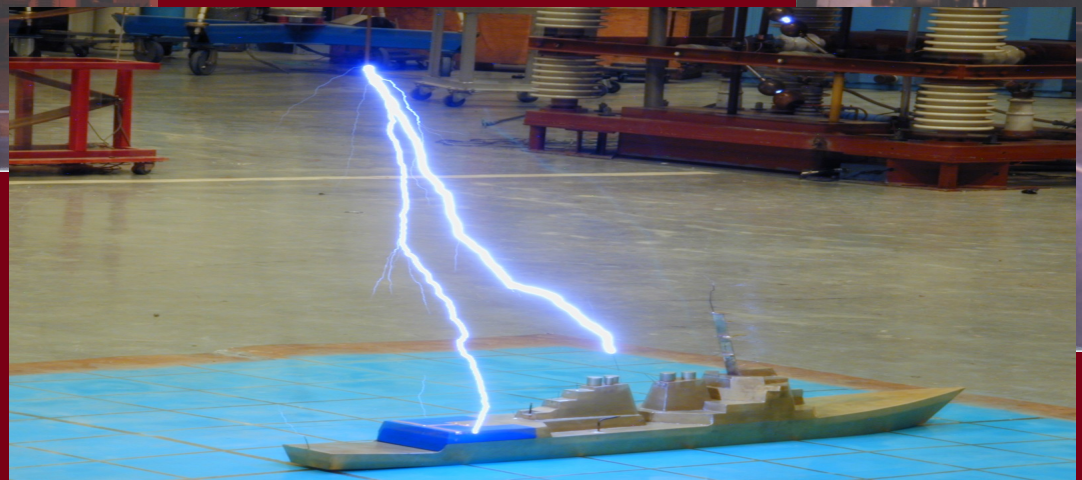
Basic Supporting Technologies

- Emerging Materials Research Laboratory (ONR)
- Computational Simulation and Design Center
- Visualization, Analysis, and Imaging Laboratory
- Center for Computational Systems
- Microsystems Prototyping Laboratory

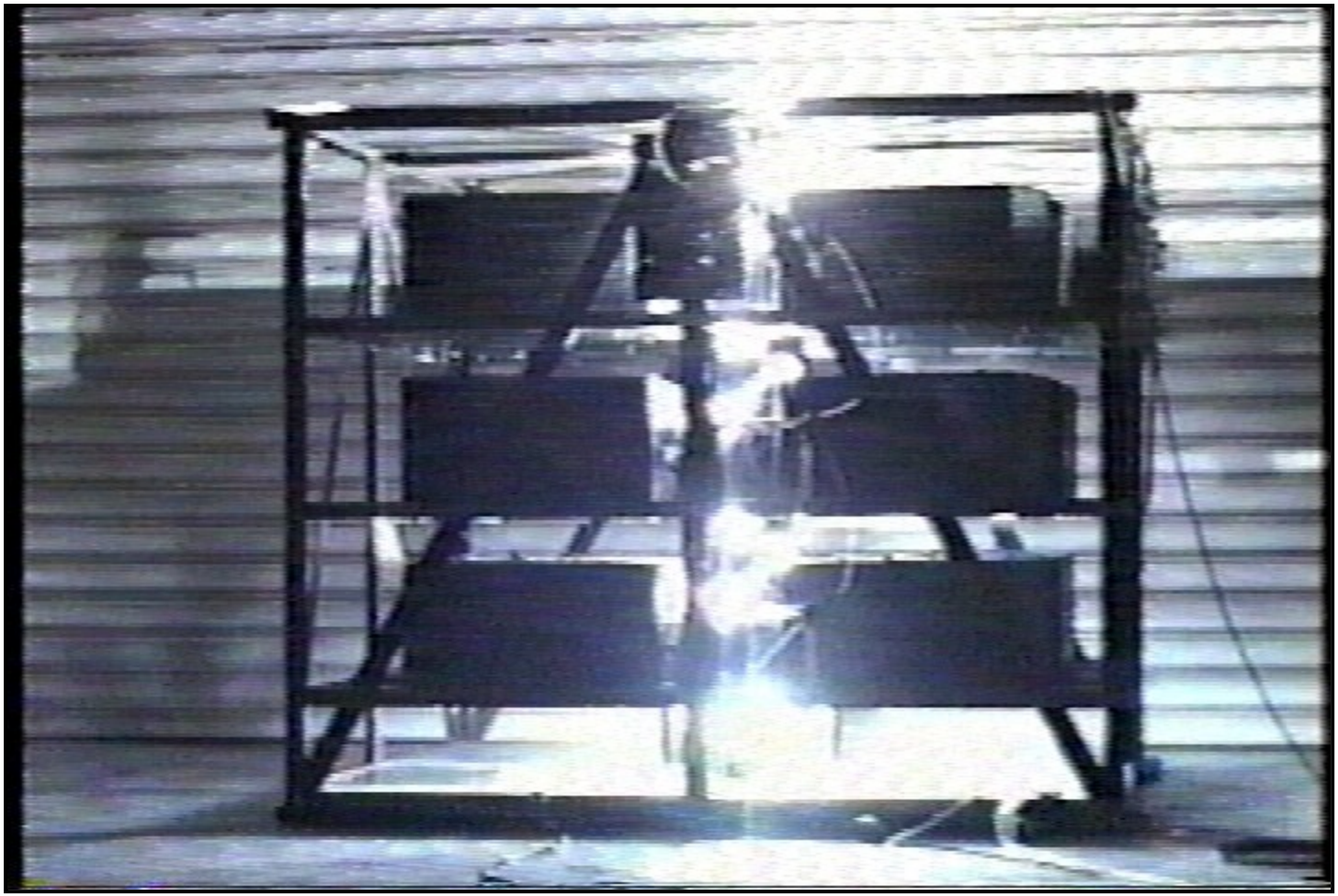
High Voltage Laboratory (HVL)







Three-Stage Marx Firing



Electric Ship Program Objective

Support the development of an all-electric ship with distributed (survivable) complex power systems for minimally-manned ships employing automatic controls and electric actuators and powering advanced pulsed loads.

MSU Objective

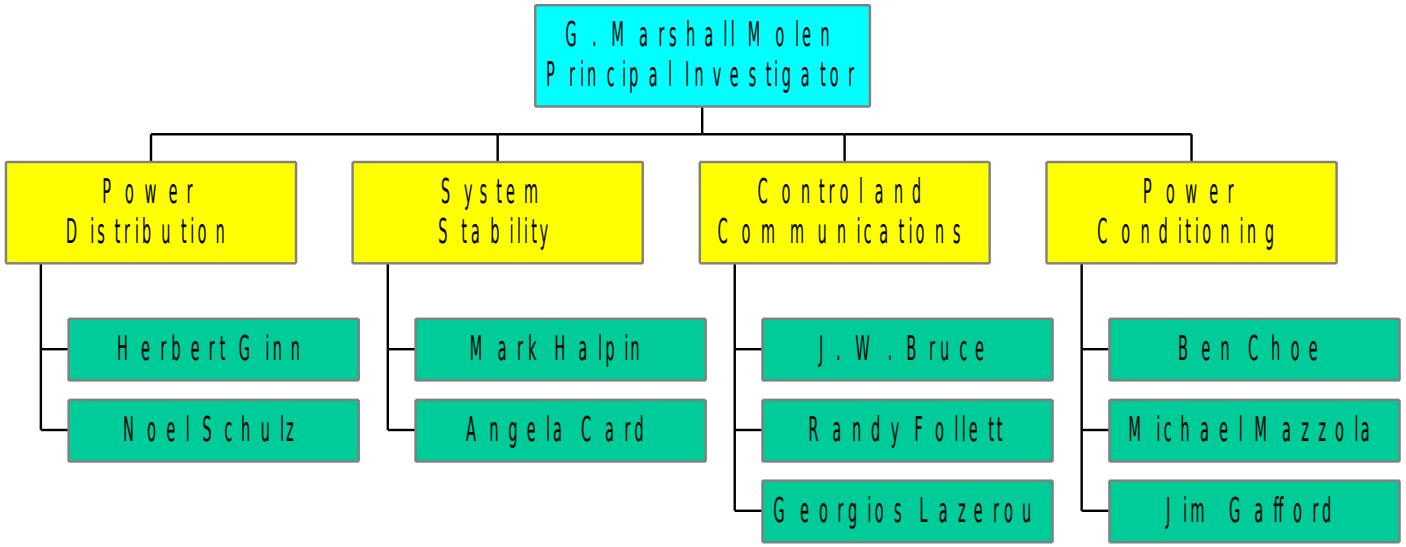
- Continue a tradition of educating the next generation of power engineers.
- Bring unique research experience to the consortium.
- Cross link with our consortium members strengths.
- Cross link with our existing research programs, facilities, and expertise, especially those that can contribute enabling technology.
- Cooperate with technology integrators, especially those with defined needs for electric power and propulsion technology.

Rational for Cross Linking to programs outside of AEPS

Common Technical Challenges with Major Programs (land, sea, air)

- Power Density
- Reliability
- Efficiency
- Maintainability
- Cost Effectiveness
- Power Distribution and Control
- Power System Integration
- Electronic Packaging and Interfacing
- Manufacturability
- Environmentally Friendly

MSU E-Ship Program



Power Distribution Tasks

- Reconfigurability
  - Figures of merit
  - Metered data requirements
- Power Quality and Power Reliability
- Common Modeling Techniques
  - ANSI/EPRI Common Information Model (CIM)
  - Multispeak
- Simulation Tools
- Coordination with control system thrust

Sensing for protection and control

- Develop list of needed and possible data acquisition monitoring requirements
- Investigate “flexible” embedded system technology to develop test cases for best hardware/software configurations
- Identify hardware needed to test flexible embedded system monitoring and control

System Stability Tasks

- Define topological model
- Evaluation of potential stability criteria
- Assessment of relative margins with respect to absolute limits

System Stability Issues

- Stability of shipboard power systems influenced by:
  - The presence of the large converter loads associated with propulsion systems.
  - The presence of significant energy storage for electromagnetic weapons and launch/recovery systems.
- Comparison to utility systems.
  - Utility systems do not supply a load consisting almost exclusively of converters.
  - Energy storage on the utility grid is virtually nonexistent.

System Stability Issues

- Converter basic science issues:
  - Linearization techniques useful or time-domain simulations required?
  - What detail required in modeling?
  - Sensitivity to changes in the power system topology or power delivery equipment (e.g. superconducting devices)?
  - Can converter controls and topologies also serve to enhance stability?
  - Can stability phenomena be bounded to simplify generalized design?
- Energy storage basic science issues:
  - Link the controls of the storage and pulse loads?
  - What energy storage beyond that needed for pulse loads?
  - Can responses be initiated ahead of time through enhanced communications?
  - How best to quantify stability enhancements?

Control Systems Tasks

- Controls and Communications
  - Reconfigurability
  - Network Infrastructure
- Control Algorithm Development
- Coordination with power system thrust

Network Architecture and Design for a Distributed Power Emulation System

- **Designed an initial network architecture for a distribu**
- **Evaluating the architecture by using emulation techni**
  - **Use general-purpose PCs to represent**
    - **nominal power components**
    - **experimental routers**
    - **control agents**
    - **sensors and actuators**
  - **Generate traffic based on the type and utilization of t**
    - **Use *NetSpec***
      - **general-purpose network traffic generator**
      - **add power and control traffic models**
  - **Use an *Emulation Manager* to control & administer ex**

Network Architecture and Design for a Distributed Power Emulation System

Purpose

- **Evaluate routing protocols (i.e., OSPF) for re-configura**
  - **Emulate faults**
  - **Improve such that network is fully adaptive and re**
- **Evaluate control functions**
- **Provide hardware-in-the-loop testing**
  - **Evaluate reconfiguration strategies for power syste**
- **Evaluate designed algorithms for data handling and re**

Power Conditioning Tasks

- Categorize pulse load terminal properties.
- Categorize energy storage properties.
- Coordinate with other tasks to predict optimal design.
- Validate where practical with empirical data.
- Conduct applications engineering in high power density power electronics.
- Support realistic “full-scale” applications.

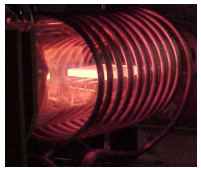
Power Electronics at Mississippi State University

Materials - Devices- Circuits - Systems

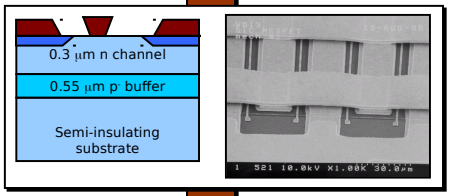
Emerging Materials Research Laboratory *EMRL*

ONR
N00014-01-C-0167
C. Wood

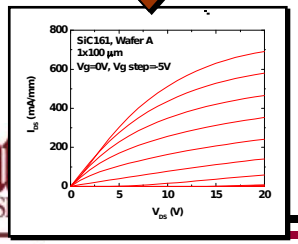
SiC Epi at MSU



MESFET Fab at GE



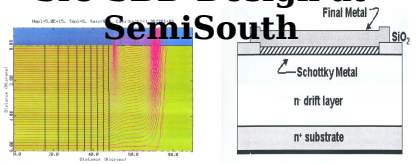
Testing at GE & MSU



Miss. Center for Advanced Semiconductor Prototyping *MCASP*

AFRL/MDA
F33615-01-D-2103
J. Scofield

SiC SBD Design at SemiSouth

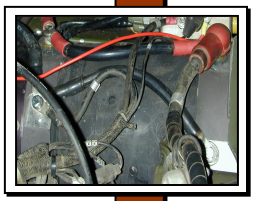


SBD Fab at MSU

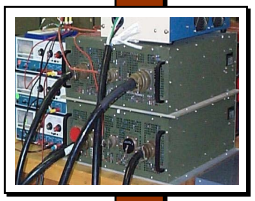
Commercial Packaging

Power Electronics Prototyping / Power Component Test Bed *PEP/PCT*

SMDC
DASG60-00-C-0074
L. Riley



Modify HMMWV at MSU



Prototype Power Electronics at MSU

Sentinel Demo by MSU/Guard/SMDC

Project Overview

Bench-level **Bench-level** **Bench-level**

Phase 1

Retrofit with SiC Schottky Diodes

Phase 1 Hardware Integration

Phase 2

Replace with SiC VJFET/Schottky Switching Module

Phase 2 Hardware Integration

Phase 3

Motor Upgrade

- Higher Bus Voltage
- Higher switching Frequency

Phase 3 Hardware Integration

Phase 4

Integrate full spectrum of power system technology improvement to

- Maximize efficiency
- Minimize size and weight

Multiple Integration Opportunities

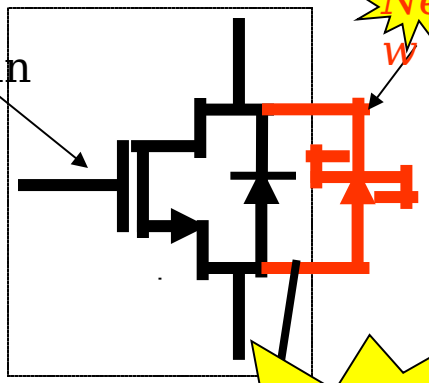
NAVOCEANO SeaHorse AUV for Navy Oceanography

- >300 nm range, 72 hr. ops.
- Disposable batteries
- Propulsion 70% load
- Improved efficiency enables
  - Rechargeable batteries
  - ~~Extended range~~
  - Added payload

Technical Overview

Phase 1

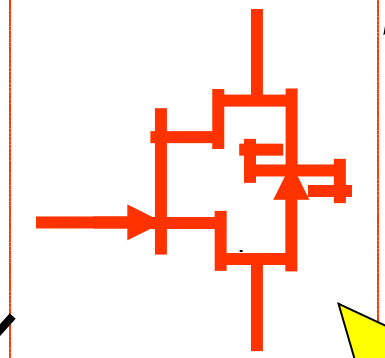
Existing



Improve Switch in Controller

Phase 2

6-pulse Inverter Module



Improve Motor & Controller

Phase 3

Upgraded Motor Controller

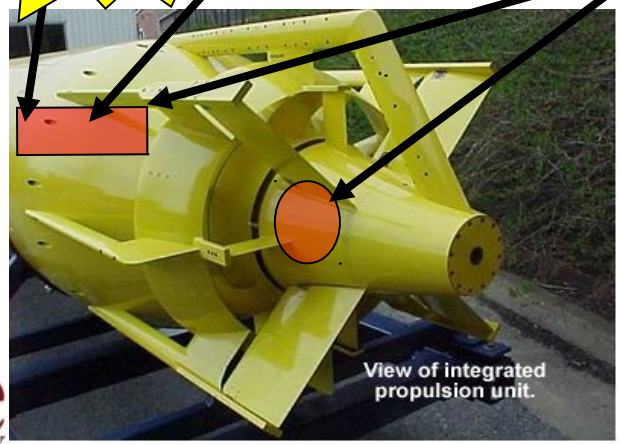
+300

-300

> 20kHz

- Increased bus voltage, decreased bus current
- Increased switching frequency, decreased motor size and weight

Motor



Phase 4

Power System Reengineered

- Battery
- Bus
- Motor Controller
- Motor

INTERGATED AS A SYSTEM INTO THE AUV

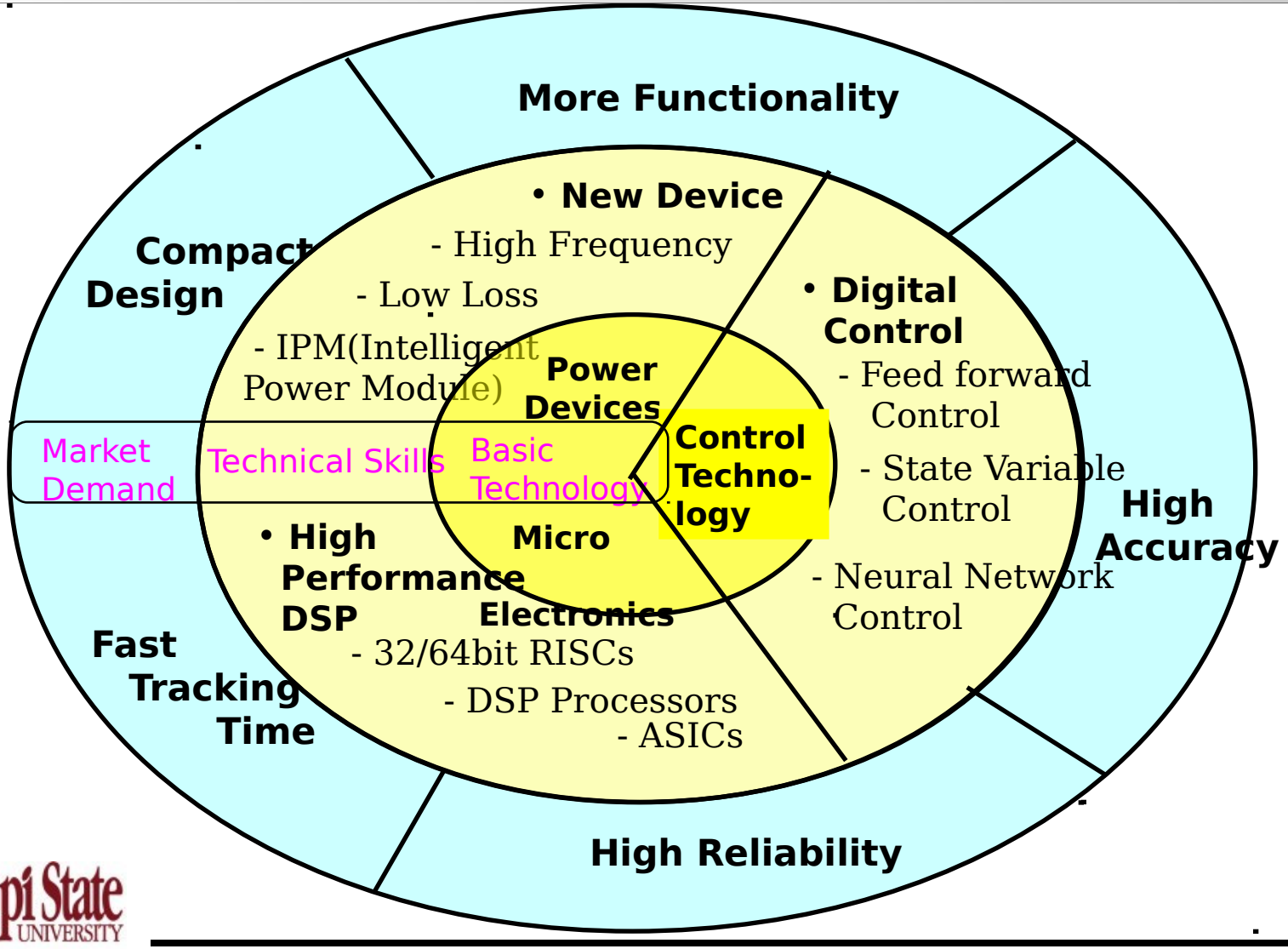
Power Electronics & Mechatronics

Mississippi State University

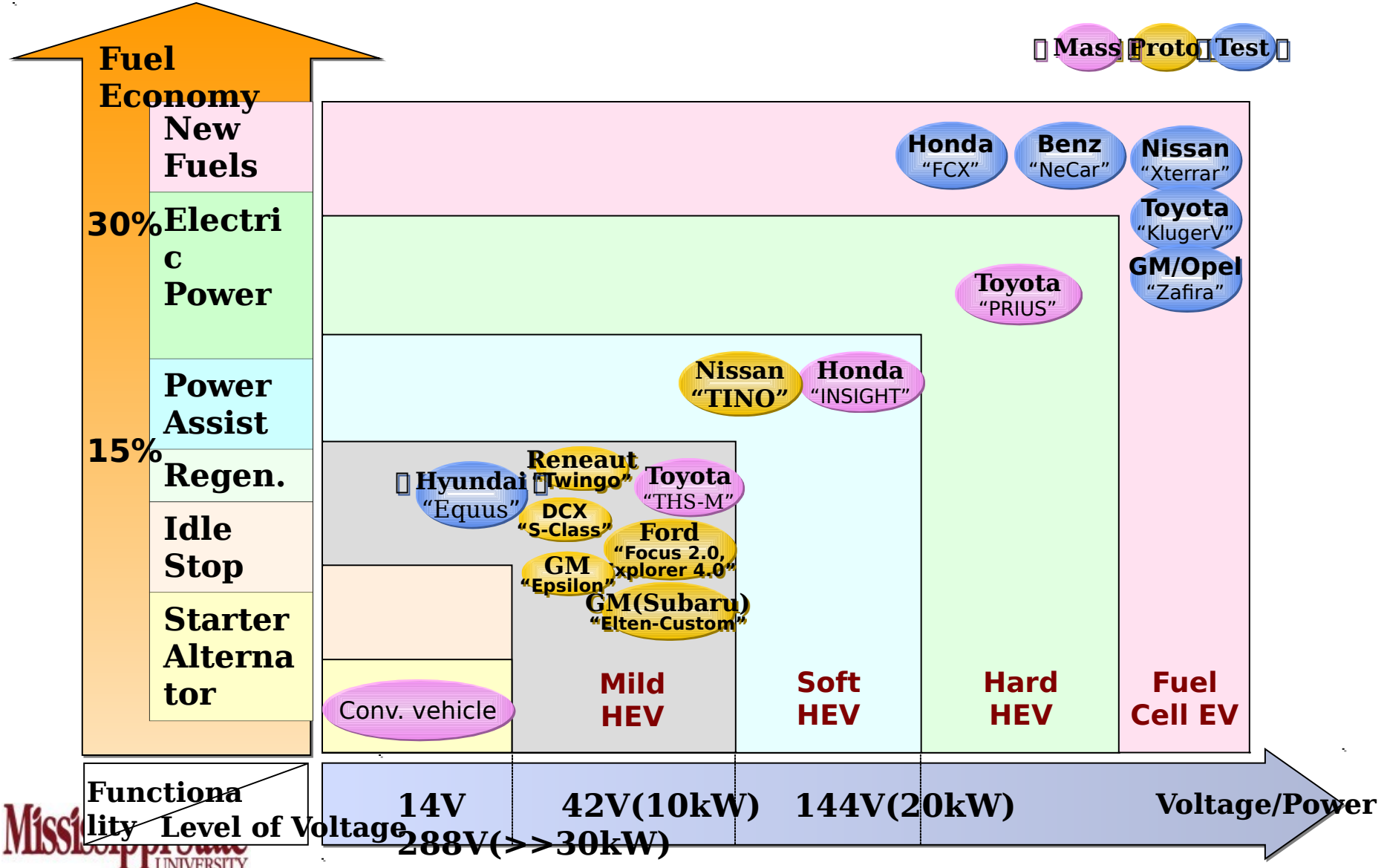
Center for Advanced Vehicular Systems

Ben S.-Y Choe

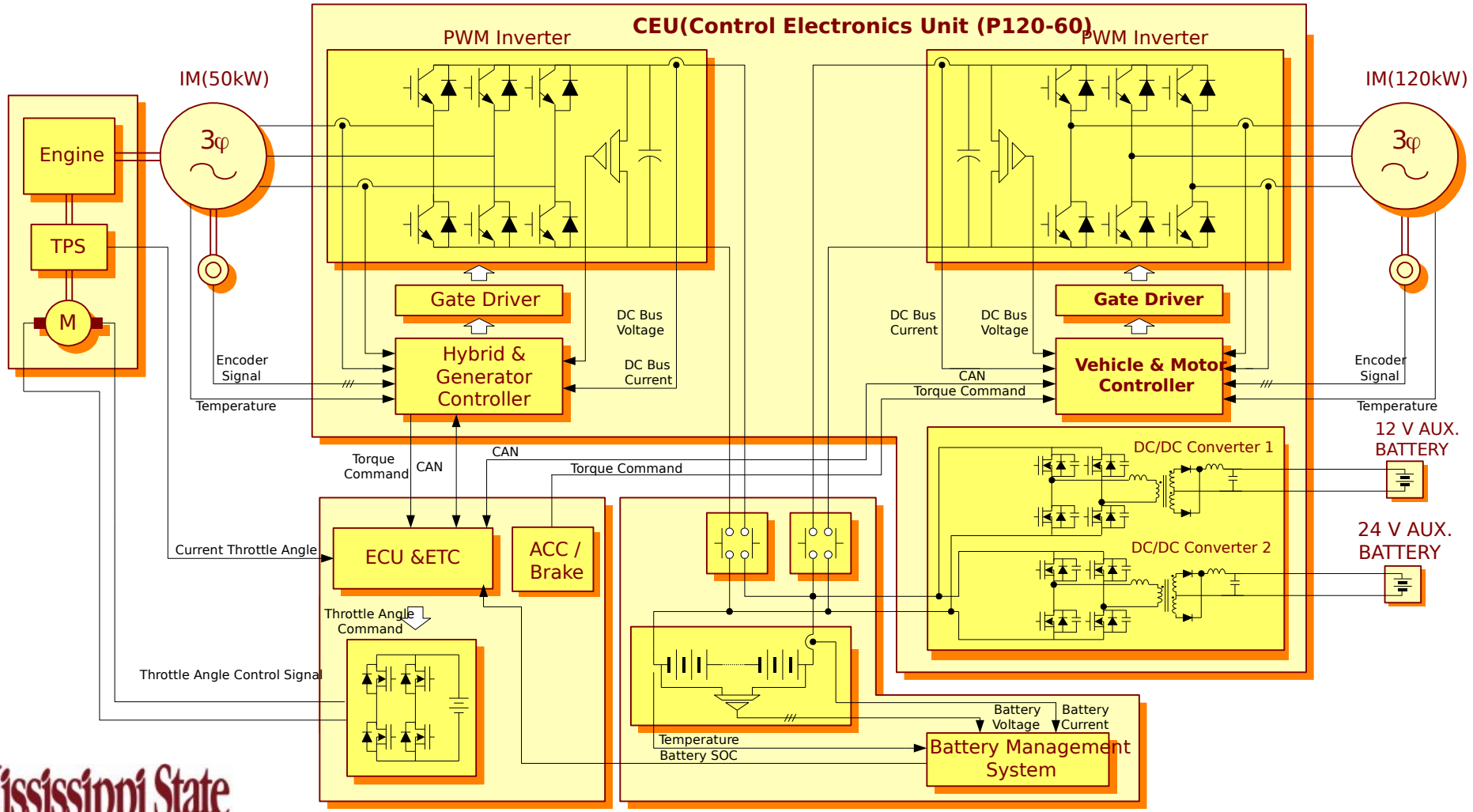
Future Development Directions



Classification of 42V/HEV/FCEV

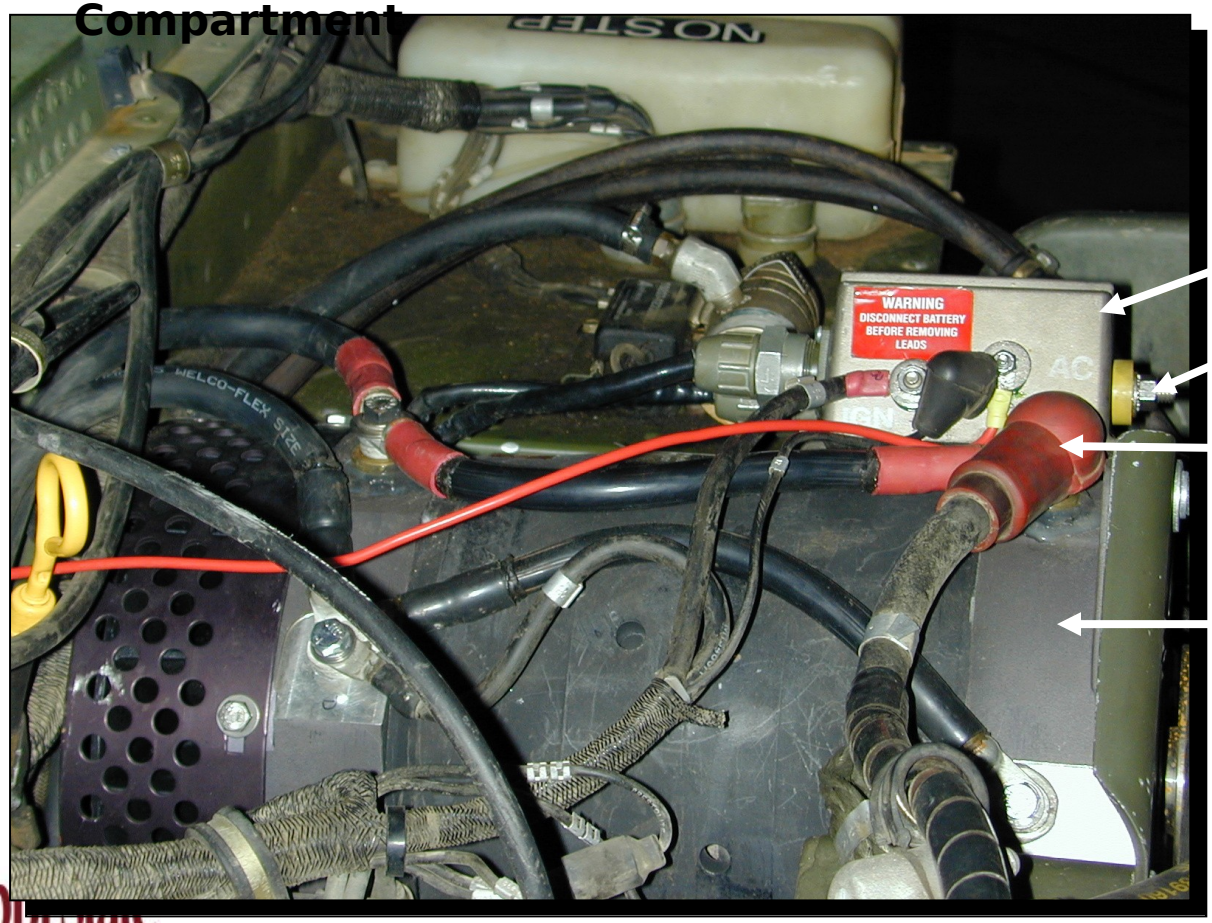


Electrical Block Diagram of SHEV System



11-kW Alternator In Conventional HMMWV at MSU (U)

Alternator Installed in HMMWV Engine Compartment

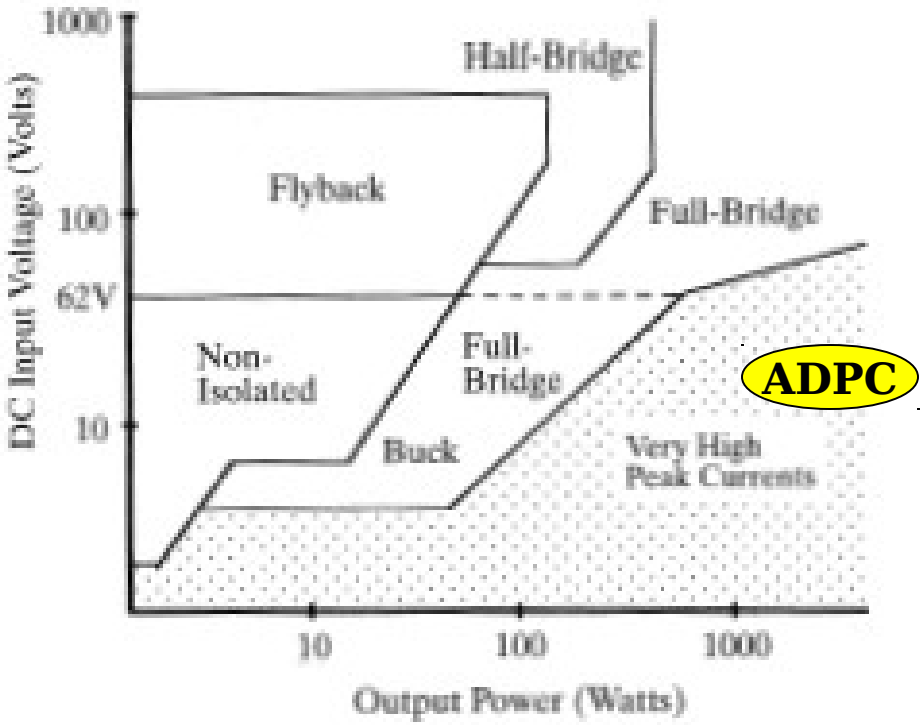


Voltage Regulator 14-V, 50-A output

28-V, 400-A output

Niehoff Alternator

Advanced Power Electronics are Enabling New Applications (U)



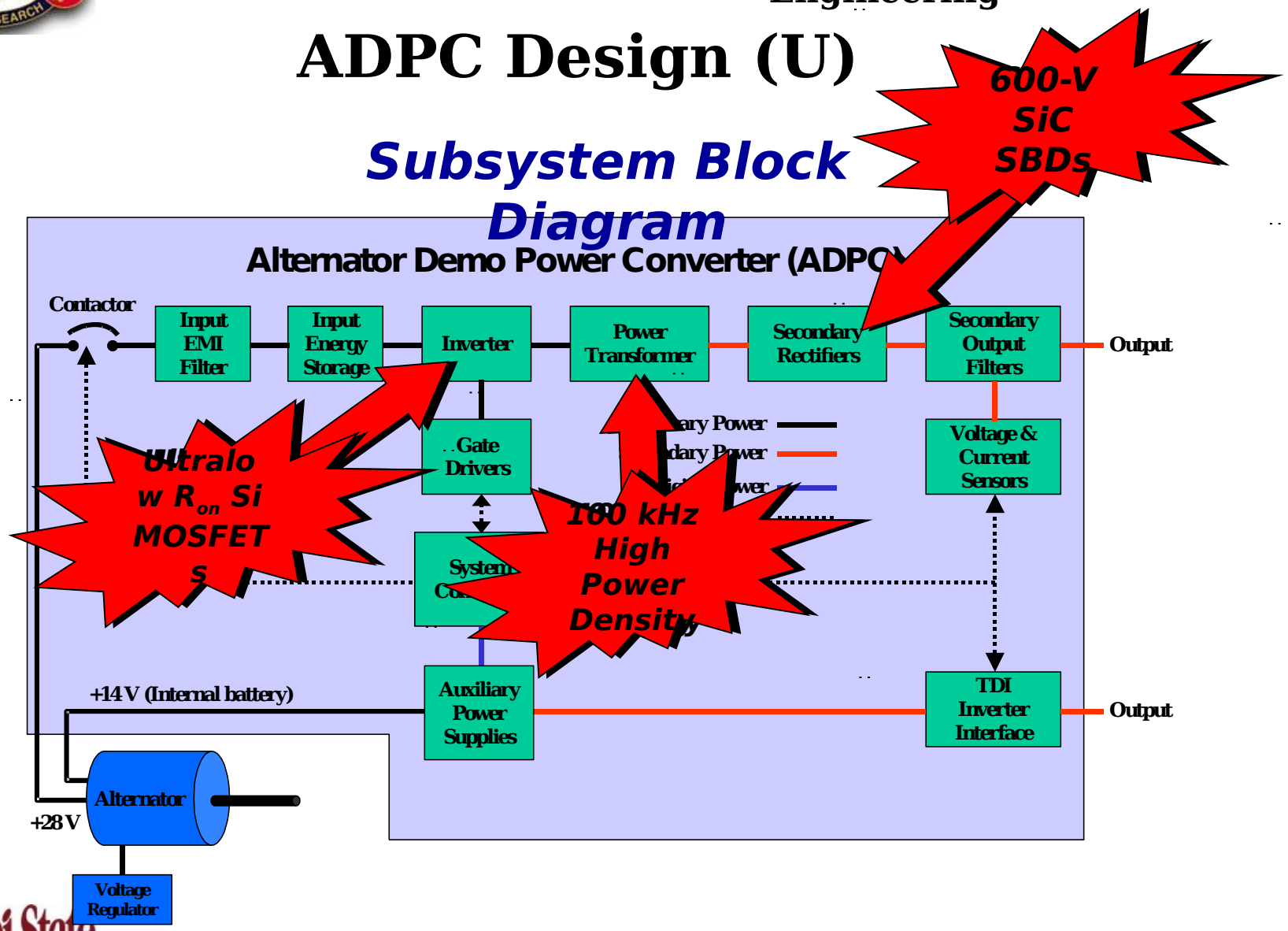
Alternator Demo Power Supply (ADPC)

Specifications

- Input voltage: 20-32 V
- Output voltage: ±200 V
- Rated Output Current: 14/16 A
- Rated Output Pwr: 5.6/6.4 kW
- Max Output Pwr: 7.0 kW
- Max Input Pwr: 10.0 kW (15 s)
- Max Input Current: 500 A (15 s)
- Nom. Input Current: 287 A @ 28 V
- Switching Frequency: 100 kHz
- Ambient Temp.: 0-65°C

ADPC Design (U)

Subsystem Block Diagram



Capstone

Sun Dancer Solar Race Car

Houston MS High School and MSU

2001 Winston Solar Challenge

Champions